APPLICATION

FOR

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TITLE: FQPSK-B VITERBI RECEIVER

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FQPSK-B VITERBI RECEIVER

[0001] The present application describes a special kind of FQPSK-B Viterbi receiver.

CROSS-RELATED APPLICATION

[0002] The present application claims priority from provisional application number 60/262,019, filed January 16, 2001.

STATEMENT AS TO FEDERALLY-SPONSORED RESEARCH

[0003] The invention described herein was made in the performance of work under a NASA 7-1407 contract, and is subject to the provisions of Public Law 96-517 (U.S.C. 202) in which the contractor has elected to retain title.

BACKGROUND

[0004] Feher's Patent QPSK ("FQPSK") is a spectrally efficient form of offset QPSK modulation which uses pulse shaping in order to reduce spectral side lobes, and cross-correlation between its in-phase("I") and quadrature phase ("Q") baseband signals, in order to maintain a nearly

constant single envelope. These characteristics of FQPSK may make this format desirable for communications in nonlinear, bandwidth-constrained channels.

[0005] A special form of FPQSK, known as FPQSK-B, is described in U.S. Patent Nos. 4,567,602 and 5,491,457. This is a baseband filtered version of FQPSK which may be useful in limited bandwidth channels. However, the bandwidth limiting of FQPSK-B comes at the expense of bit error rate degradation; that is; FQPSK-B is more spectrally efficient than unfiltered FQPSK, but may have intersymbol interference due to the baseband filtering. For example, a traditional receiver for FQPSK-B may have a bit error rate of 1.4 dB at 10^{-3}.

[0006] FQPSK-B signals may be demodulated using symbol-by-symbol detection. This kind of demodulator may be formed of a detection filter along with a sample and hold circuit.

[0007] While this forms a simple circuit, the demodulating circuit does not take sufficient advantage of the "memory" that is inherent in FQPSK-B signals. Because of this memory between signals, Viterbi demodulation may be optimum for this type of modulation. Viterbi modulation may provide better bit error rate performance.

[0008] A trellis coded interpretation of FQPSK is known. The FQPSK signal is generated by transmitting one of 16

different shaped waveforms. The basic waveform shapes are shown in Figure 1. Eight unique waveforms are shown in Figure 1. Eight other shapes, which are the negatives of those waveforms, are also used. These waveforms form a 16 state trellis.

[0009] A full-blown system of this type, however, may be too complex for a real implementation.

SUMMARY

[0010] The present application teaches a special Viterbi receiver which has reduced complexity but still has bit error rate advantages over a symbol-by -symbol detection type receiver. According to an embodiment, the waveforms forming the FQPSK-B waveforms are grouped in a special way to create a simpler trellis. This receiver may provide significant gain over conventional FQPSK-B receivers, while reducing the complexity that would otherwise be inherent in an FQPSK-B Viterbi receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] These and other aspects will now be described in detail with reference to the accompanying drawings, wherein:

[0012] Figure 1 shows waveforms for a conventional FQPSK system;

[0013] Figure 2 shows a graph with a comparison of bit error rates for different FQPSK receivers;

[0014] Figure 3 shows a block diagram of a conventional Viterbi receiver;

[0015] Figure 4 shows a set of averaged waveforms for the Viterbi receiver;

[0016] Figure 5 shows a block diagram of a simplified FQPSK-B receiver of an embodiment; and

[0017] Figure 6 shows a trellis diagram for the simplified FQPSK-B receiver.

DETAILED DESCRIPTION

[0018] The present invention defines a reduced complexity alternative system. This system may form a simplified FQPSK-B Viterbi receiver with a reduced number of correlators. For example, the receiver may have a factor of 4 fewer correlators in the receiver, and a factor of 8 fewer algorithm branch computations.

[0019] In an embodiment, the 16 possible FQPSK-B waveforms are divided into 4 groups. Each group may include signals, for example, which have some similar characteristic. A FQPSK signal is received. This signal

is correlated against the average of the waveforms in each group. The signals are appropriately grouped, as described herein, in a way that reduces the FQPSK trellis from a 16 state trellis with 4 transitions per state into two independent two-state trellises with only two transitions per state. Due to the similarity between the FQPSK-B waveforms, this reduced-complexity receiver only has a small E_b/N_o penalty as compared with a full-blown Viterbi receiver. However, it offers significant performance gains as compared to the conventional FQPSK-B receiver. Special characteristics of this receiver are hence described.

[0020] A traditional commercial FQPSK-B receiver includes a sample and hold receiver that carries out symbol by symbol detection. The received signal is downconverted to baseband. The baseband signal is then filtered using a detection filter whose bandwidth-symbol period (BT_s) is approximately 0.6. The output of the detection filter is sampled, and a decision about contents is made about the specific signal.

[0021] The intersymbol interference may increase the bit error probability of this receiver. Figure 2 shows a comparison between the 32 term theoretical approximation of

bit error probability, and the computer simulated results. Figure 2 shows a comparision with ideal FQPSK.

[0022] A traditional FQPSK-B Viterbi receiver is shown in Figure 3. This receiver may correlate the baseband received signal with the FQPSK waveforms, and uses a Viterbi technique in order to perform trellis coding. The Viterbi technique may search through the 4 transitions of the 16 states of a FQPSK trellis. The Viterbi Algorithm branch metrics Z_j are defined as follows:

$$Z_j = R_j - \frac{E_j}{2} \qquad j = 0, \ldots, 15 \tag{1}$$

[0023] where R_j is the correlation of the received signal and the jth waveforms, E_j is the energy in the jth waveform. The correlation values R_8 through R_{15} are obtained by taking the negatives of R_0 through R_7 respectively. For example, $R_0 = -R_8$. A total of 16 correlators are needed, with 8 correlators being needed for the in phase signals and 8 correlators being needed for the quadrature phase signals. The "Viterbi Algorithm" block 350 may carry out the subtraction of $E_j/2$ from the value R_j.

[0024] A simplified FQPSK-B Viterbi receiver is described with reference to Figures 4 and 5. In this embodiment, sets of waveforms are grouped together in order to create a reduced trellis. In the embodiment, the

waveforms C_0, C_1, C_2 and C_3, effectively the top row in Figure 1, are grouped into a first group. As can be seen by investigating these waveforms, each of the waveforms have similar properties. For example, C_0-C_3 each represent waveforms which are primarily towards the top of the graph. C_4-C_7 represent waveforms which extend from the bottom of the graph on one side to the top of the graph on the other side. That is, these waveforms are spectrally similar, so that the combinations of these waveforms may also be spectrally similar to each of the waveforms being averaged. A second group is formed of the second row in Figure 1, including the waveforms C_4, C_5, C_6 and C_7. Similarly, the third group of waveforms is formed of C_8-C_{11}, and a fourth group of waveforms is formed of C_{12}-C_{15}. This grouping enables the trellis coded structure to be divided into two independent, in phase and quadrature, two-state trellises.

[0025] Figure 5 shows a block diagram of the modified receiver. The received signal 500 is filtered by 502 and demodulated by demodulator 504. The demodulated signals include an in phase signal 508 and quadrature signal 509. The in phase signal 508 is delayed by a half symbol by delay element 507. The demodulated signal is correlated against the average of the waveforms in each group. Four correlators 510, 512, 514, 516 are used for this

correlation. The average values are shown in Figure 4, and obtained as:

$$q_0(t) = \frac{1}{4}\sum_{i=0}^{3} C_i(t) \qquad q_2(t) = -q_0(t)$$
$$q_1(t) = \frac{1}{4}\sum_{i=4}^{7} C_i(t) \qquad q_3(t) = -q_1(t)$$

(2)

[0026] q2 and q3 are respectively the negatives of q_0 and q_1. Hence, only two correlators are needed for each of the I and Q channels. The same Viterbi Algorithm metric is used as in equation 1, except that Ej which is used is the energy of the group average waveform $q_j(t)$.

[0027] Figure 6 shows a trellis including group signals with two states and two transitions in each state. The dual Viterbi techniques for the I and Q channels can hence be combined into a single 4 state VA. Compared with the full Viterbi receiver, this simplified receiver may have 12 fewer correlators, and an eight fold reduction in the number of Viterbi Algortihm computations per decoded bit.

[0028] Although only a few embodiments have been disclosed in detail above, other modifications are

possible. All such modifications are intended to be encompassed within the following claims, in which: